FOREST PEST MANAGEMENT
Pacific Southwest Region

34,02212 -116.86866

Report No. 82-4

3430 Evaluation
August 30, 1982

A BIOLOGICAL EVALUATION OF THREE YEARS OF PEST-CAUSED TREE MORTALITY ON THE SAN BERNARDINO NATIONAL FOREST

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ABSTRACT

A three-year survey of tree mortality on the San Bernardino National Forest (from 1976 to 1978) showed annual mortality losses to be 0.06 trees with 33 bd.ft. per acre. Most mortality (75%) was the result of insects and diseases acting together as pest complexes to kill the tree. White fir, Jeffrey pine, and Coulter pine were the main tree species killed. Jeffrey and western pine beetles, the fir engraver, flatheaded borers, annosus root disease, dwarf mistletoes and true mistletoe were the pests responsible for most of the mortality. Mortality levels were lower than usual due to very favorable rainfall prior to and during the survey period. An integrated pest management approach to prevent or reduce tree mortality is recommended. In application this approach considers the current and probable activities of all pests, including insects and diseases, as part of all Forest and District land management planning, with the result that appropriate pest management activities (prevention, detection, evaluation, and control of all serious pests) become an integral part of forest and stand management.

INTRODUCTION

The San Bernardino National Forest, lying just east of the Los Angeles Basin, has the highest visitor use of any National Forest in the United States. Six million visitor-days of use were recorded in 1976. This use is concentrated on a relatively small area of about 120,000 acres of forest land in the ponderosa - Jeffrey pine, mixed conifer and Coulter pine types. The management goals and objectives for the Forest are centered chiefly around maintaining this limited and heavily used forest land for recreational and watershed-related uses, rather than around commodity production uses like timbering.

The major vegetation management goal of the Forest is to support the recreation use by protecting and maintaining an attractive, safe, and healthy forest. Timber management activities such as planting, thinning, harvesting, and salvage logging are required and practiced to accomplish this goal.

The Forest has a long history of pest-caused tree mortality involving bark beetles, dwarf mistletoe and more recently air pollution (ozone). The past bark beetle control efforts consisted of 1) high-risk logging to remove from the stands those trees highly susceptible to bark beetles, and 2) suppression of bark beetle populations by the prompt falling and treating of currently bark-beetle infested trees to kill the developing brood within the infested tree. Some dwarf mistletoe suppression in the form of pruning and thinning also was done.

Recently questions have been raised regarding 1) the desirability of removing some of the largest, more picturesque trees from the recreation stand in the process of high-risk logging, 2) the need for and effectiveness of the bark beetle suppression program, and 3) the role of other insects and diseases and stand and site factors which may be contributing to the tree mortality, directly by killing trees or indirectly by predisposing the trees to bark beetle attack.

In 1976, a three-year survey of insect- and disease-caused tree mortality was begun on the San Bernardino National Forest with the goal of providing information that would help answer the questions above. The objectives of the survey were to:

1) Measure the amount of tree mortality each year for the three-year period, May 1975 to May 1978.

2) Identify the insects and pathogens that were, separately or in combination, reponsible for that mortality.

3) Identify the stand, site, and host conditions that were associated with killing agents.

The data used in preparing this evaluation were gathered in a cooperative effort by the University of California at Berkeley, the San Bernardino National Forest and Forest Pest Management, Pacific Southwest Region, Forest Service.

A separate but complementary two-year (1977 and 1978) survey of insect and disease-caused mortality on private lands within and adjacent to the San Bernardino National Forest was conducted in cooperation with the California Department of Forestry. The results of this private-land survey and the management implications will be documented in a separate report.

METHODS

A stratified random sampling survey design (Pest Damage Inventory) was used. The survey area included 61,250 acres of ponderosa and Jeffrey pine type, 39,675 acres of mixed-conifer type, and 18,557 acres of Coulter pine type, of National Forest land on the San Bernardino National Forest.

Photo Plot Selection. Forest-type maps (each covering one township) were divided into 81 rectangular units of approximately 284 acres each. The acres of forest type (ponderosa-Jeffrey pine, mixed conifer, and Coulter pine) were estimated using a dot grid over the type map of each potential photo plot. Units with less than 50 acres of any sample type were discarded. Photo plots were selected randomly until a five percent minimum sample was obtained for each type. After discarding a small number of plots without replacement, because of changes in type due to wildfire, 19 plots (2423 acres) of ponderosa - Jeffrey pine type, 20 plots (2678 acres) of mixed conifer type and 15 plots (1810 acres) of Coulter pine type were selected as photo plots.

Aerial Photography and Photo Interpretation. Photographs of each photo plot were taken in May of each year. The photos were taken with 9 1/2" wide Ektachrome MS film (type 2448) at a scale of 1:8000 with 75% overlap to provide for stereoscopic viewing. A Zeiss RMK camera with an 8 1/4" lens, a HF 3 or 4 haze filter, and an antivignetting filter were used.

Aerial photos were examined for dead tree groups as follows: the forest type (ponderosa-Jeffrey pine, mixed conifer, or Coulter pine) was delineated on the center photograph of each triplet of photos, and the photographs were viewed stereoscopically at 4x to 8x magnification. Within the photo plot each tree or group of trees that appeared yellow to sorrel on the photos was encircled on the photograph. (The yellow to sorrel color is an indication of recent death of a tree.) The photo interpreter counted the dead trees in each group and estimated species and size class. For the 1977 and 1978 interpretation, a check was made of the dead trees or group using photographs taken the preceding year to verify that the trees had died during the year just prior to photography.

Ground Survey. Single dead trees and groups of dead trees detected on the photo plots were visited on the ground within a few months following photography. Since the total number of dead trees detected on the photos was small, all dead trees were visited.

Data collected for each dead tree group included stand composition, basal area measured with a 20 factor prism, the number of dead trees in the group, the species, height and diameter of each tree, and the year in which each tree died. The year of death was estimated from the color and condition of the foliage and from examining aerial photographs taken the previous year.

Pest data were collected for all trees that had faded during the year prior to photography. Trees were examined systematically for symptoms and signs of foliage, stem, and root insects and pathogens.

Insects and pathogens were listed as the cause of death, or as contributors to death, when they met certain criteria. For example, Fomes annosus was listed as a contributor when the typical stain, decay or conks were found on the dead tree, or other trees in the same disease "center." The presence of the pathogen was verified by laboratory culturing in questionable cases. Armillaria mellea was included when a dead oak was present on the site near enough to provide inoculum and when signs of the fungus were present on the dead tree. When both A. mellea and F. annosus were present, only F. annosus was listed. Dwarf mistletoes were called contributors to death when the disease rating of any tree was four or more using Hawksworth's six point system. Dendroctonus jeffreyi, D. brevicomis, and Scolytus ventralis were listed when their distinctive galleries indicated their presence and a successful attack of the tree. The roundheaded fir borer (Tetropium abietis) and the California flatheaded borer (Melanophila californica) were listed when their galleries were present and when bark beetles considered to be more aggressive were absent.

Statistical analysis

Variable probability sampling (probability proportional to sample size) was generally employed for both selection of the plots to be ground checked and subsequent selection of mortality spots to be visited on these plots. An exception to this was for the 1978 selection of the ponderosa-Jeffrey pine and Coulter pine types, where because of the low number of mortality spots, a complete ground sampling of all photo plots and their associated mortality spots was done.

For variable probability sampling (pps) the mortality and associated standard error were determined for each stratum as follows:

First estimate the current tree mortality for each of the ground checked plots (V_i) by the formula:

$$V_i = \frac{C_i}{N_i} \sum_{j=1}^{M_i} \frac{X_{ij}}{C_{ij}} t_{ij}$$, where:

t_{ij} = the number of times spot j was chosen within photo-plot i.

M_i = the total number of spots ground checked on photo-plot i.

$N_i = \sum_{j=1}^{M_i} t_{ij}$

X_{ij} = the number of dead trees on spot j on photo-plot i as determined by visiting spot j.

C_{ij} = the number of dead trees on spot j on photo-plot i as counted by photo interpretation.

C_i = the number of dead trees on photo i as counted by photo interpretation.

Second, estimate the total mortality (V) for each stratum by the following formula:

$$V = \frac{K}{M} \sum_{i=1}^{M} \frac{Vi}{Ci} \quad \text{, where:}$$

M = the total number of photo-plots ground checked, including redundancies.

Ci = the number of dead trees on photo-plot i as counted by the photo interpreter.

$$K = \frac{\text{(total acres of stratum) x (total photo-interpreted mortality)}}{\text{acres sampled in stratum photo interepreted}}$$

Finally, estimate the standard error by the following formula:

$$S.E. = \sqrt{VAR} \quad \text{, where:}$$

$$VAR = \frac{K^2}{M(M-1)} \left(\sum_{i=1}^{M} \left[\frac{V_i}{C_i} \right]^2 - \frac{\left[\sum_{i=1}^{M} \frac{V_i}{C_i} \right]^2}{M} \right)$$

In the cases where complete sampling of all photo plots and mortality spots was done (1978), the total mortality (V) and associated standard error (SE) were determined as follows:

$$V = \frac{\text{(total acres in stratum) x (total mortality by visiting)}}{\text{acres sampled}}$$

$$SE = \sqrt{VAR} \quad \text{, where:}$$

$$VAR = \left[\frac{\text{total acres}}{X} \right]^2 \left[\frac{S_Y^2 + (R^2 \times S_X^2) - 2RS_{XY}}{n} \right]$$

where:

X = average photo plot size

S^2y = variance of mortality from photo-plot to photo-plot.

S^2x = variance of acreage from photo-plot to photo-plot.

Sxy = covariance of mortality with acreage.

R = proportion of mortality to acres sampled.

n = number of photo plots sampled.

RESULTS

Levels of Mortality

An estimated 21,400 trees with an average dbh of 17-18 inches and a total volume of 11 million board feet died on the 119,482 acres surveyed during the sampling period: three years for the ponderosa-Jeffrey pine and mixed conifer types, and two years for the Coulter pine type. The estimated annual tree mortality for all three types was 6,910 trees containing 3.5 million board feet (Table 1). Jeffrey pine, white fir, and Coulter pine were the major tree species which died, accounting for 93% of the dead trees and 91% of the volume during the survey period. The estimated mean annual tree mortality was 0.06 $\pm$ 0.01 trees per acre (Table 2) with a mean volume per acre of 33 $\pm$ 5.0 board feet (Table 3).

Pest Causes of Mortality

The causes of mortality varied for each tree species. In most cases the diagnosis indicated that both insects and diseases, acting together as complexes, were responsible for the trees' deaths. The term "pest complex" is used to describe the cause of death when two or more pests are involved in the killing of a host.

An estimated 78% of the dead white fir were killed by pest complexes (Figure 1). The insect/root disease and insect/root disease/mistletoe pest complexes were responsible for 74% of the total white fir mortality. The species of insects and pathogens involved in these pest complexes and responsible for the white fir mortality are listed in Table 4. Either the fir engraver beetle (Scolytus ventralis), the roundheaded fir borer (Tetropium abietis), or both infested nearly all white firs killed during the three-year period. The two root pathogens, Fomes annosus and Armillaria mellea, and true mistletoe (Phoradendron bolleanum) were the pathogens associated with a large proportion of the fir mortality.

Insect/disease complexes were responsible for 68% of the Jeffrey pine mortality (Figure 2). Insect/injury and insect alone categories were responsible for 29% of the Jeffrey pine mortality. The most important insects involved in the mortality were the Jeffrey pine beetle (Dendroctonus jeffreyi), the California flatheaded borer (Melanophila californica), engraver beetles (Ips spp.), and the red turpentine beetle (Dendroctonus valens) (Table 5). Two root diseases (F. annosus and A. mellea), dwarf mistletoe (Arceuthobium campylopodum), and Elytroderma needlecast (Elytroderma deformans) were the major diseases associated with the death of Jeffrey pine.

Insects acting alone were diagnosed as causing 61% of the Coulter pine mortality (Figure 3). Western pine beetle (D. brevicomis) and dwarf mistletoe were the insect and disease agents most commonly associated with the death of Coulter pine (Table 6). The western pine beetle was involved in over 90% of the Coulter pine mortality.

The general causes of the total mortality of all species and the volume killed are presented in Figures 4 and 5, respectively. Insect/disease complexes were diagnosed as the cause of about three-fourths of the annual total trees killed (Figure 4) and two-thirds of the annual volume killed (Figure 5). Insects alone accounted for 20% of the deaths and 24% of the volume killed. Diseases alone killed 1% of the trees containing 3% of the volume.

Table 1. MEAN ANNUAL TREE MORTALITY IN ALL FOREST TYPES FOR THE THREE-YEAR SURVEY PERIOD FOR THE MAJOR TREE SPECIES KILLED.

TREE SPECIES	NUMBER DEAD TREES	VOLUME (MBF)	VOLUME/TREE (BOARD FEET)
White Fir	2408	544	226
Jeffrey Pine	3112	2,683	862
Coulter Pine*	1390	274	197
Total	6910	3,501	

* A two-year mean obtained from the 1977 and 1978 data.

Table 2. MEAN ANNUAL NUMBER OF TREES KILLED PER ACRE ON THE SAN BERNARDINO NATIONAL FOREST DURING THE SURVEY PERIOD.

TYPE	NO. TREES/ACRE/YEAR 1976	1977	1978	THREE YEAR AVERAGE
PINE	.159 ± .015	.036 ± .004	.054 ± .004	.074 ± .008
MIXED CONIFER	.056 ± .003	.045 ± .012	.037 ± .010	.046 ± .009
COULTER PINE		.078 ± .029	.067 ± .009	.072 ± .019
ALL TYPES	.12 ± .01	.05 ± .01	.05 ± .004	.06 ± .01

P = 61,250 Acres

MC = 39,675 Acres

CP = 18,557 Acres

Table 3. MEAN VOLUMES OF KILLED TREES ON THE SAN BERNARDINO NATIONAL FOREST DURING THE SURVEY PERIOD.

FOREST TYPE	VOLUME/ACRE/YEAR (BD. FT.) 1976	1977	1978	MEAN ANNUAL VOLUME/ACRE (BD. FT.)
Pine	80 ± 17	30 ± 7	12 ± 3	40 ± 6
Mixed Conifer	50 ± 9	20 ± 4	13 ± 4	28 ± 4
Coulter Pine	———	19 ± 6	15 ± 5	17 ± 4
All Types	68 ± 11	25 ± 4	13 ± 2	33 ± 5

FIGURE 1. THE PERCENTAGE OF THE MEAN ANNUAL WHITE FIR MORTALITY ATTRIBUTED TO INSECT/DISEASE COMPLEXES.

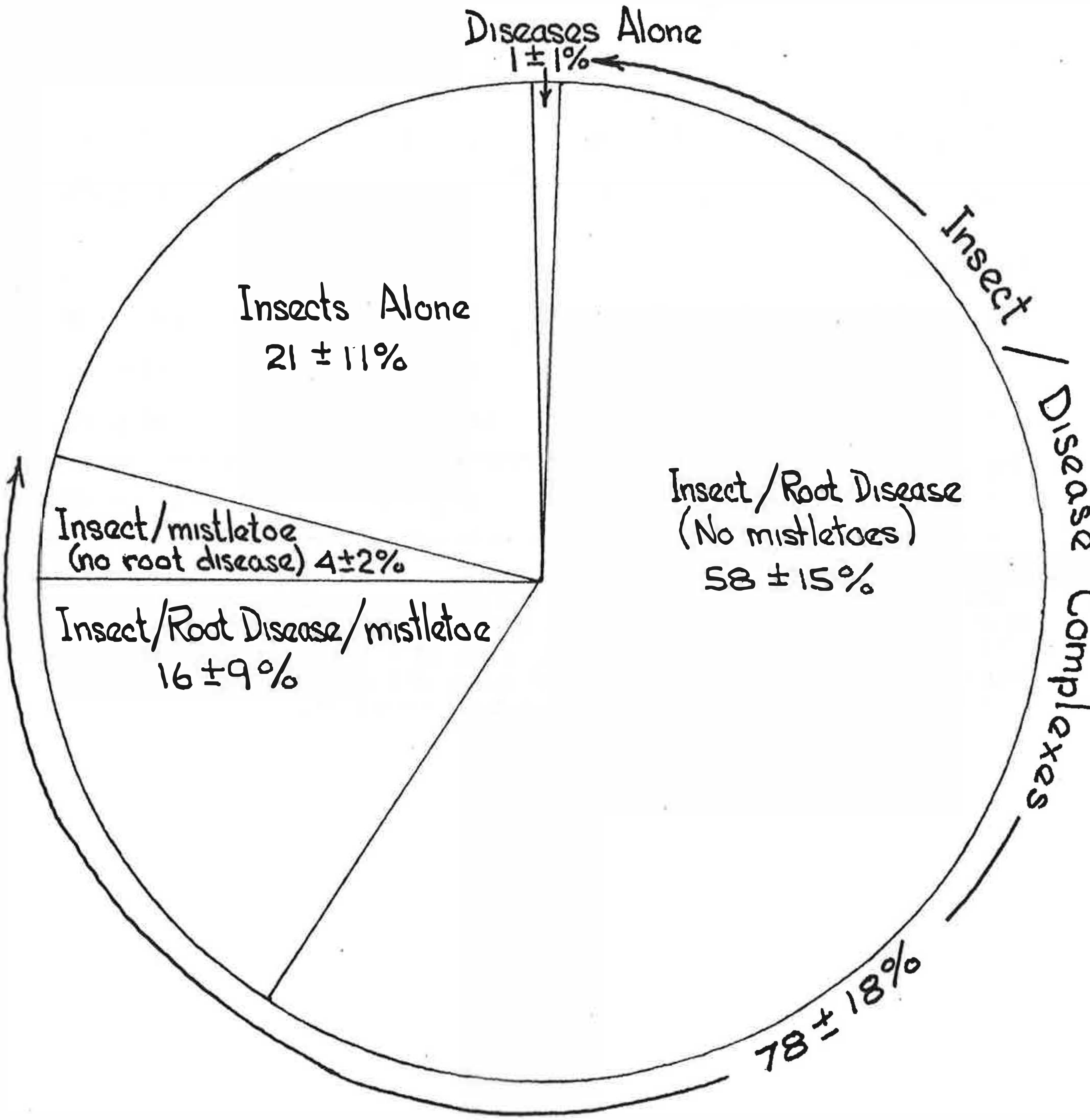


Table 4. INSECTS AND DISEASES CONTRIBUTING TO WHITE FIR MORTALITY

	MEAN ANNUAL TREE MORTALITY				
	DEAD TREES		VOLUME		VOLUME/TREE
	NO.	%	MBD. FT.	%	BD. FT.
Insects					
S. ventralis	2307 ± 331	96	512 ± 128	94	214 ± 43
T. abietis	460 ± 86	19	119 ± 37	22	318 ± 104
Pathogens					
F. annosus	1509 ± 225	63	360 ± 76	66	240 ± 48
A. mellea	261 ± 165	15	24 ± 12	4	233 ± 198
P. bolleanum	461 ± 174	19	141 ± 65	26	188 ± 81
TOTAL FIR MORTALITY	2408 ± 333	100	544 ± 128	100	226 ± 42

These amounts of tree and volume mortality are those which the individual pests were completely or partially responsible for killing. In the case where pest complexes (multiple pests) were responsible for tree death, the tree and its volume are listed under each of the pests in the complex. Hence the sum of the columns for dead trees and for volume by individual pest listing is greater than the listed total tree mortality.

FIGURE 2. THE PERCENTAGE OF THE MEAN ANNUAL JEFFREY PINE MORTALITY ATTRIBUTED TO INSECT/DISEASE COMPLEXES.

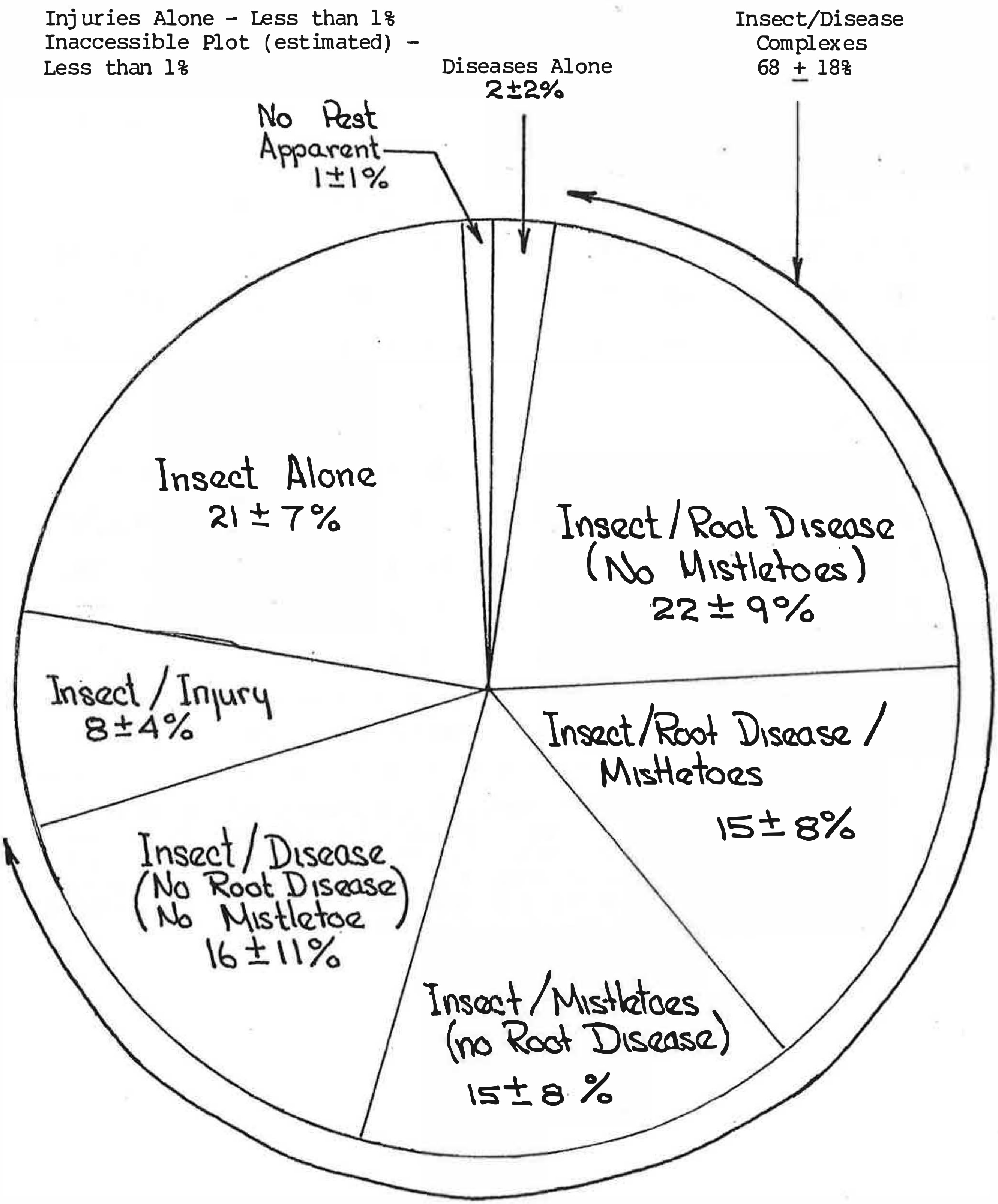


Table 5. INSECTS AND PATHOGENS CONTRIBUTING TO JEFFREY PINE MORTALITY

	MEAN ANNUAL TREE MORTALITY				
	DEAD TREES		VOLUME		VOLUME/TREE
	NO.	%	MBD. FT.	%	BD. FT.
Insects					
D. jeffreyi	2010 ± 379	66	1,550 ± 267	58	811 ± 131
M. californica	995 ± 275	33	733 ± 311	27	434 ± 144
Ips spp.	632 ± 77	21	734 ± 352	27	836 ± 335
D. valens	33 ± 15	1	64 ± 31	2	643 ± 307
Pathogens					
F. annosus	895 ± 265	30	312 ± 95	12	437 ± 165
A. mellea	96 ± 75	3	10 ± 8	1	134 ± 108
A. campylopodum	906 ± 273	30	1,039 ± 425	39	1,027 ± 343
E. deformans	503 ± 332	17	305 ± 214	11	202 ± 142
P. schweinitzii	5 ± 5	1	5 ± 5	1	324 ± 324
TOTAL JEFFREY PINE MORTALITY	3112 ± 398	100	2683 ± 352	100	862 ± 81

These amounts of tree and volume mortality are those which the individual pests were completely or partially responsible for killing. In the cases where pest complexes (multiple pests) were responsible for tree death, the tree and its volume are listed under each of the pests in the complex. Hence the sum of the columns for dead trees and for volume by individual pest listing is greater than the listed total tree mortality.

Figure 3. THE PERCENTAGE OF THE MEAN ANNUAL COULTER PINE MORTALITY ATTRIBUTED TO INSECT/DISEASE COMPLEXES.

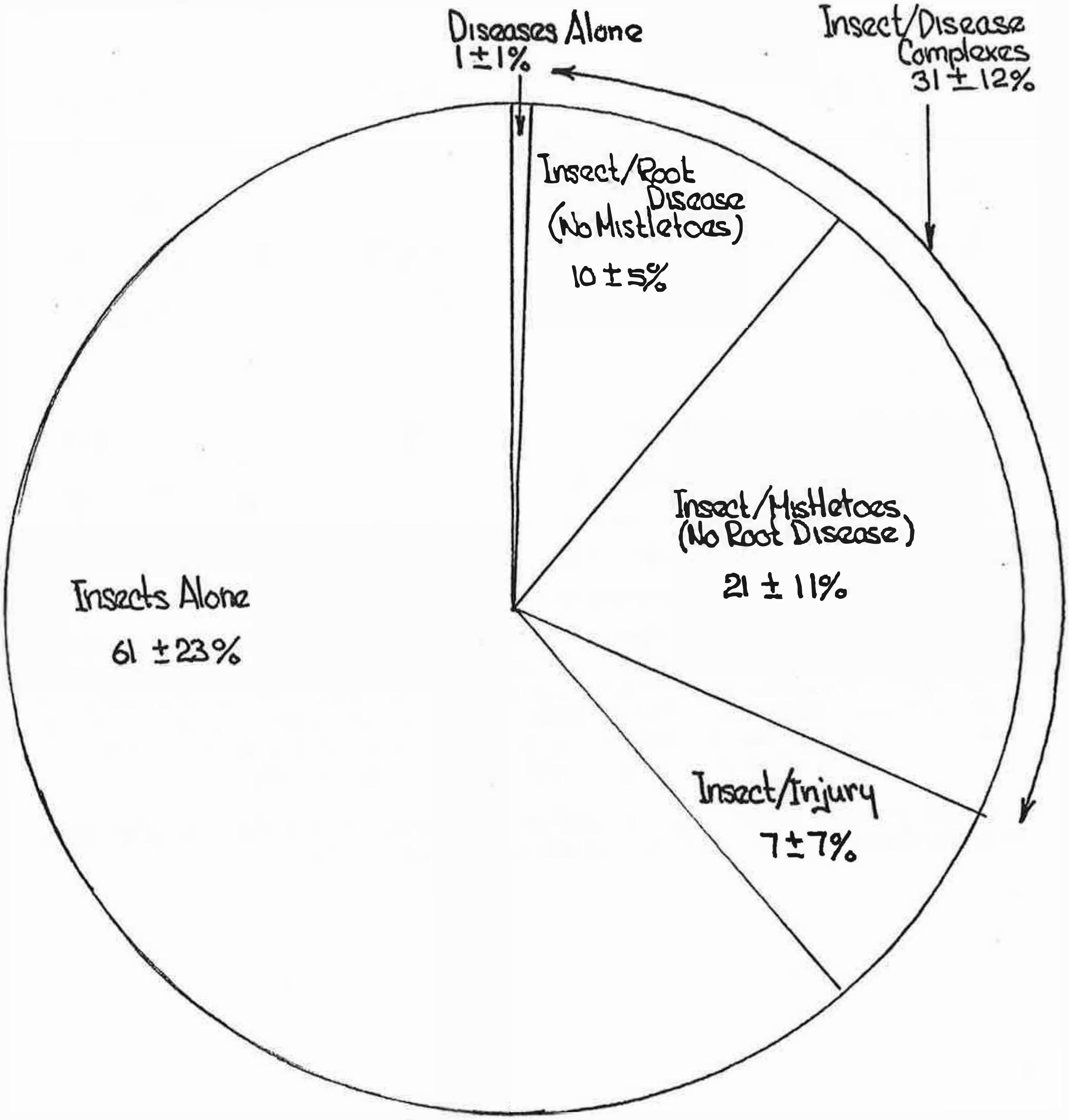


Table 6. INSECTS AND PATHOGENS CONTRIBUTING TO COULTER PINE MORTALITY.

	MEAN ANNUAL TREE MORTALITY				
	DEAD TREES		VOLUME		VOLUME/TREE
	NO.	%	MBD. FT.	%	BD. FT.
Insects					
D. brevicomis	1146 ± 299	94	208 ± 42	96	184 ± 39
M. californica	102 ± 72	8	13 ± 12	6	74 ± 65
D. monticola	38 ± 71	3	10 ± 6	4	125 ± 80
D. valens	181 ± 71	15	38 ± 16	18	105 ± 45
Ips spp.	119 ± 60	10	11 ± 7	5	90 ± 57
Pathogens					
F. annosus	64 ± 40	7	14 ± 11		206 ± 147
A. campylopodum	263 ± 108	22	47 ± 18		166 ± 58
TOTAL	1390 ± 299	100	274 ± 42	100	197 ± 36

These amounts of tree and volume mortality are those which the individual pests were completely or partially responsible for killing. In the cases where pest complexes (multiple pests) were responsible for tree death, the tree and its volume are listed under each of the pests in the complex. Hence the sum of the columns for dead trees and for volume by individual pest listing is greater than the listed total tree mortality.

1/ Eighty-eight percent of the Coulter pine died in the Coulter pine type. The remainder was in the pine and mixed conifer types.

Figure 4. THE PERCENTAGE OF THE MEAN ANNUAL MORTALITY OF ALL TREE SPECIES ATTRIBUTED TO INSECT/DISEASE COMPLEXES.

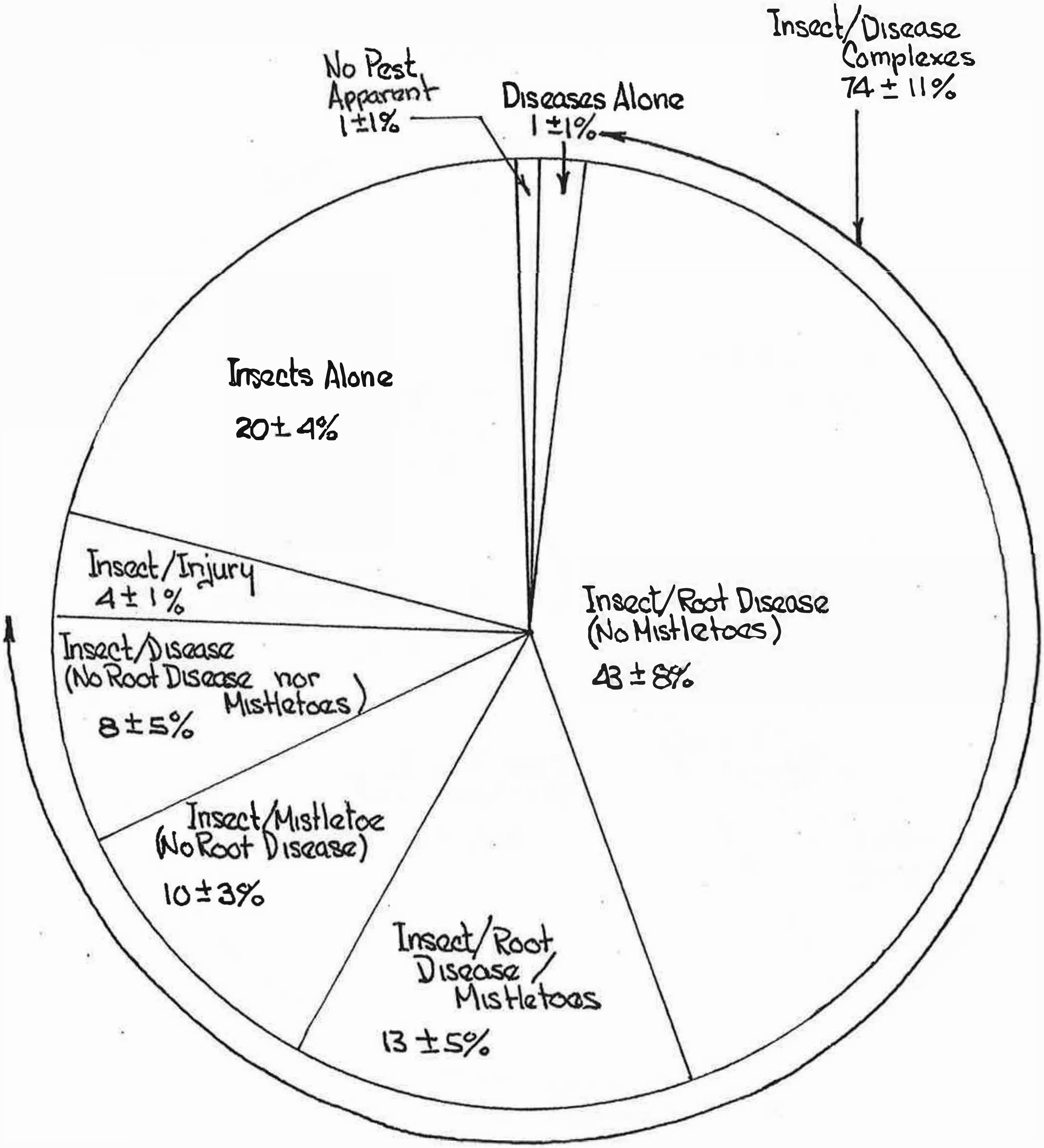
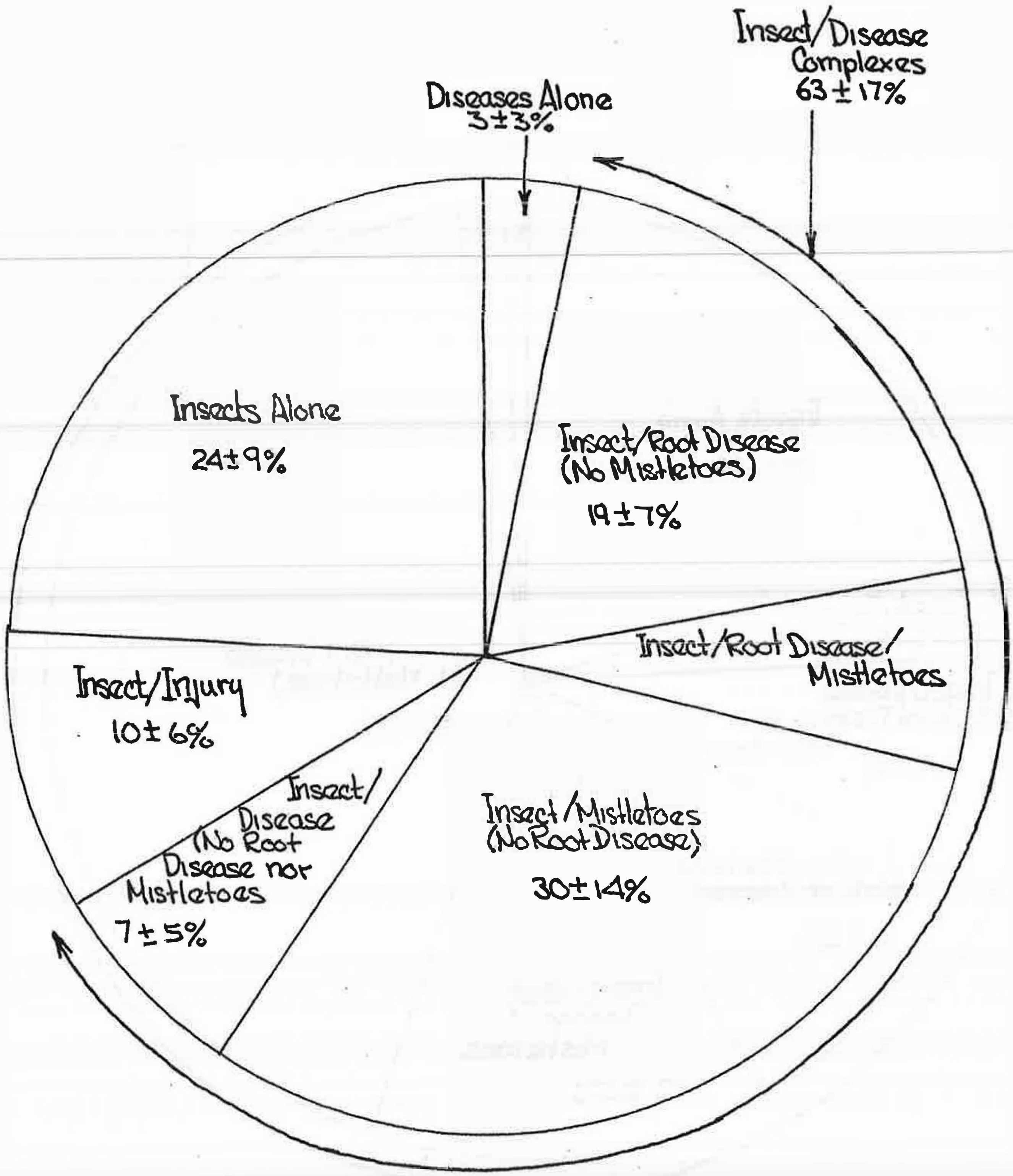


Figure 5. THE PERCENTAGE OF THE MEAN ANNUAL VOLUME LOSS OF ALL TREE SPECIES ATTRIBUTED TO INSECT/DISEASE COMPLEXES.



DISCUSSION

The economic and aesthetic values of trees are not well defined and established in those forest areas, like the San Bernardino National Forest, which are managed mainly for recreation and watershed purposes. It is generally agreed that tree cover in this kind of setting is valued for its shade, visual effects, support of wildlife and prevention of soil erosion. But there is no widespread agreement as to what a single tree in this setting is worth or, in many cases, how much a tree by itself contributes to the afore-mentioned forest aesthetic and environmental factors. It is, therefore, difficult to determine the values lost to insect- and disease-caused tree mortality and to establish thresholds for economically significant pest-caused damage.

In the absence of economic measures and thresholds, we can look for other terms in which to state pest management objectives. One such general objective is to maintain or improve the forest tree cover of the recreation forest. Viewed in the light of this statement, the 1976-78 tree mortality of 0.06 trees per acre per year over the three-year period does not seem excessive. The average volume loss of 33 board feet per year represents a loss of about 20 percent of the average growth of 160 bd. ft. per acre. Thus, at this level of tree mortality, the forest in general is growing faster than it is being killed.

However, the 1976-1978 survey period is considered to be a period of below-normal mortality. Past experience indicates that the tree mortality levels were considerably higher in the years prior to the survey. Our data reinforce this by showing a trend toward reduced mortality from 1976 to 1978. The survey years, 1976 to 1978, were all years of normal or above-normal rainfall. Our experience in southern California indicates that the level of tree mortality increases greatly during periods of low rainfall and high moisture stress. Thus, it is our opinion that because of the above-normal rainfall during the 3 years of the survey period, tree mortality was low and continued to decline in response to the abundant moisture, and that tree mortality will increase significantly during the next local drought period.

Also, tree losses at specific locations within the Forest were much higher than the mean for the entire Forest. In some cases, particularly in high-use recreation areas, the mortality exceeded acceptable levels, indicating that prevention and control efforts were needed even under the most favorable precipitation conditions.

<u>Appropriate Control Procedures</u> (Past Efforts in Light of Results)

Nearly all past pest control efforts have been aimed at control of dwarf mistletoes or 3 groups of cambium-feeding insects of pine: the bark beetles (<u>Dendroctonus</u> spp.), the engraver beetles (<u>Ips</u> spp.), and the

flatheaded borers (Melanophila spp.). The insect control efforts used were suppression for the pine bark beetles and the flatheaded borers, and prevention for the pine engraver beetles. The suppression efforts were aimed at reducing beetle populations by killing the insect brood in currently infested trees so that they could not emerge and attack adjacent pines. This was accomplished by falling the infested trees and removing them from the forest, peeling and burning the bark, or spraying the bole with residual insecticides to kill the brood insects they contained.

The prevention effort against the engraver beetles was aimed at decreasing the amount of breeding material, usually fresh slash, available to the engraver beetles early in the season so that large populations were not available in the late summer and early fall to attack the pine hosts when they were the most susceptible.

The San Bernardino National Forest stopped direct control (maintenance control) efforts on the National Forest lands in July of 1975 about the same time we started this 3-year analysis of tree mortality on the Forest. In the absence of this kind of control, we have the opportunity to look at the kinds of trees killed and the pests responsible for their death, and to reason what portion of the mortality might have been prevented if the maintenance control program had been continued.

On the average, 34 percent of the dead trees were white fir. White firs are attacked and killed by pests different from those killing the pines. The control strategies developed for pine insects have not been tested on fir insect pests, and from what we know about their biology, would most likely be ineffective. So the white fir mortality, representing 34% of the total mortality, would not have been prevented by the continuation of maintenance control.

The western pine beetle and the Jeffrey pine beetle, against which maintenance control is used, were not the only pests found attacking and killing the pines. Tree diseases, most commonly root diseases and dwarf mistletoes, were involved as predisposing or weakening agents in 68% of the Jeffrey pine mortality; and no insects were found in another 3% of the dead Jeffrey pine. These trees, killed or severely weakened by other pests, would not have been saved for an extended period as a result of a maintenance control effort: we reason that within a few years the other pests themselves would have killed the pines or they would have been attacked by bark beetles which survived suppression efforts or which flew in from non-suppression areas. This 71% of the annual Jeffrey pine mortality amounts to 2148 trees, leaving 877 (29%) Jeffrey pines that were apparently killed by insects alone, and which maintenance control might have prevented from dying due to bark beetle attack.

In Coulter pine, 31% (389 trees) of the mortality involved diseases and 69% (827 trees) insects alone. Thus, 69% of the Coulter pine might have been protected by direct bark beetle suppression. These two pine species, accounting for almost all of the pine mortality, had a total of 1704 trees for which direct beetle population suppression might have prevented death. This amounted to 26% of the total tree mortality. As with any pest suppression method, however, maintenance control does not eliminate bark

beetles from the woods. And, because factors other than disease also predispose trees to beetle attack - such as stresses associated with overstocking, injury, disturbance, and a general decline in health/vigor related to aging - it is reasonable to assume that some additional proportion of these 1704 trees also would have died, despite a maintenance control effort. Therefore, it is our conclusion that these maintenance control efforts of the past, alone, are inadequate for the current tree mortality conditions, because they are aimed at and could affect only a minor portion of the pest-caused tree mortality.

PEST MANAGEMENT PRESCRIPTIONS

In the past, pest control efforts on the San Bernardino and other southern California National Forests have been aimed largely at suppression of a few of the more apparent insects and diseases. These suppression efforts consisted of: 1) dwarf mistletoe control mainly through the removal or pruning of infected trees, 2) direct suppression of bark beetles by removal and/or chemical treatment of infested trees and 3) the logging of high-risk trees. Furthermore, these control efforts have not been adequately coordinated with one another or forest management practices.

The most recent Timber Management Plan calls for the management of stands under the selection system, single tree and group selection, to meet the forest management goals and the specific stand management objectives. Treatment methods are aimed at maintaining a stand structure that includes the following:

1. All or irregular size classes.
2. Old growth trees retained as long as possible.
3. Controlled stocking levels.
4. Mixed species composition.
5. Healthy, vigorous trees.
6. A near natural appearance.

That new Plan, influenced in part by preliminary survey results of this evaluation, calls for an integrated approach to pest management. Results of this survey indicate that this approach is appropriate. The integration of pest management considerations into stand prescriptions should bring about and maintain a low level of tree mortality during years of average or above-average rainfall, and prevent widespread tree mortality during periods of drought. However, higher levels of chronic tree mortality will continue in certain situations, especially in existing root disease centers, in overused and abused recreation stands, and in stands with trees that are high insect risk and/or heavily infected with dwarf mistletoe.

Specific components of an integrated pest management system that appear appropriate include the following:

1. Borax stump treatment. *Fomes annosus* was involved in a substantial proportion of both fir and pine mortality. Where present, it plays a key role in predisposing trees to successful insect attack. New infections can be prevented by applying borax to freshly cut stumps. Treatment of all freshly cut conifer stumps appears prudent.

2. Thinning. Thinning to decrease tree competition and maintain vigor is an effective stand treatment for the prevention of bark beetle-caused mortality. Thinning lowers competition between trees, reducing moisture stress, and results in the leave trees being more resistant to bark beetle attack. This beneficial effect of thinning is especially apparent during periods of stress, such as years of below-normal precipitation.

Thinning can also be an important tool for minimizing the effects of dwarf mistletoe. This pathogen becomes especially damaging in stands that stagnate. Spacing control allows the trees to grow proportionally faster in height than the parasite grows upward in the tree.

Basal area thinning guidelines are not available for specific pests. However, it is reasonable to expect that a level of thinning that results in the maintenance of good radial growth, height growth and a full crown will make the trees more resistant to insect attack and killing.

3. Sanitation. Sanitation involves the treatment or removal of hosts or host parts which are, or most likely will be, infested by forest pests and will become a threat to the residual stand. The objective of a sanitation project is to protect the residual stand. Examples of sanitation are: the removal of dwarf mistletoe infested overstory to protect the surrounding understory from future infection; removal or treatment of pine slash infested with engraver beetles to protect the surrounding pine stand from engraver beetle attack; the removal or treatment of trees infested with bark beetles or primary borers to protect adjacent trees; and the removal of badly damaged trees (lightning struck, injured from logging, etc.) which are likely to become infested with bark beetles and become the foci for infestations. Thinnings provide an excellent opportunity to practice sanitation in the forest stand.

4. Mixed Species Stands. No feasible means of eradicating *F. annosus* from an infection center are known, so centers of mortality can be expected to enlarge indefinitely as roots of susceptible trees become infected at the margins of the center. The effects of the fungus can be minimized, however, through the use of resistant species. Most hardwoods are resistant to the disease, and naturally occurring species such as black oak can be successfully grown in openings created by the disease. In addition, circumstantial evidence indicates that pines are more resistant to this fungus than firs in the mixed conifer type. It has been observed that the fungus does not often spread from diseased white firs to ponderosa pine in mixed conifer stands, even when pine is present within fir annosus centers.

Species conversion is also a good dwarf mistletoe management technique. Given the narrow host range of most of the dwarf mistletoe species, it is frequently possible to encourage non-host species when thinning or planting. Sugar pine, white fir, incense cedar and the oaks, for example, are all immune to A. campylopodum.

The opportunities for species conversion are obviously greater in the mixed conifer type than in either of the pine types. Survey results indicate that damage and the needs for pest management are greatest in the Jeffrey pine type. The presence of annosus root disease, dwarf mistletoe, and air pollution injury on Jeffrey pine, in a place like Barton Flats, for example, creates a difficult management challenge.

True fir is an understory to pine in some stands within the pine type. This condition may be even more prevalent in the future under selection management, since fir is shade tolerant. It does not seem advisable to encourage this trend, however. Observations suggest that annosus root disease may be especially damaging to white fir growing under these marginal conditions, and that extensive white fir mortality occurs on pine sites from annosus root disease and other causes during periods of low precipitation. This is particularly evident when fir grow from pole size to sawtimber size and, as individuals and stands, have demands which the marginal site cannot meet.

5. Overstory Removal. Dwarf mistletoe infected overstory trees present a special threat to susceptible trees growing nearby. Dwarf mistletoe seeds are forcibly discharged and land in the crowns of understory trees. Infections in the upper crown are especially damaging to the tree. It may be necessary to remove infected overstory trees in order to assure the life of the future stand. This is best done on an individual tree or small group basis, which fits well into Forest Plans to manage by group selection.

6. Individual Tree Protection. Some individual trees may be valued highly enough to warrant the cost of protective treatment. Locations of such trees typically are around buildings and in developed recreation sites. Situations when such treatment may be appropriate are those where: 1) trees are to be protected until they recover from injury (construction, accident, fire etc.); and 2) the lives of trees are to be extended (until they produce a seed crop, for example, or as long as possible in the case of trees that are "monarchs", or otherwise extraordinary). One form of protective treatment is the prophylactic use of insecticide to prevent likely mortality from bark beetles. Another form is pruning out "witches' brooms" caused by dwarf mistletoe, to increase tree vigor and resistance to bark beetle attack.

Integrated forest pest management success depends heavily on the integration of appropriate pest prevention and reduction measures with tree and stand manipulations. Typically, we look upon well-written silvicultural prescriptions as the vehicles for incorporating pest management into vegetation management to achieve the objectives of resource managers. The

above suggestions are available options that may or may not be appropriate to use in given situations. The specific prescriptions combining pest and forest management are written by the forest manager in light of the needs of the stand, and the objective for the individual stand.